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"Review On: Spectrum Sensing in Cognitive Radio Using Multiple Antenna"

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Abstract

As the deployment of new wireless devices and applications is growing rapidly there is an increase in demand for wireless radio spectrum. Researchers show that more than 70% of available spectrum is not used efficiently. For efficient utilization of spectrum we need to know whether the spectrum is used by primary user or not which is called Spectrum Sensing. The concept Cognitive Radio is proposed to address the issue of spectrum efficiency. In this paper, we consider various spectrum sensing techniques using multiple antennas. Multiple antenna technique for wireless communication provide better transmission with higher data rates. Simulations show Pd Vs Pfa and Pmd Vs Pfa

Keywords: *Cognitive Radio, Spectrum sensing, Spectrum sensing Techniques, Energy Detection, Multiple antennas.*

1. Introduction

Due to the rapid growth of wireless communications, more and more spectrum resources are needed. Most of the spectrum bands are exclusively allocated to specific licensed services. However, a lot of licensed bands, such as those for TV broadcasting, are underutilized, resulting in spectrum wastage. This has promoted Federal Communications Commission (FCC) to open the licensed bands to unlicensed users through the use of cognitive radio (CR) technology.

There have been many factors that have lead to development of cognitive radio technology. One of the major factor is utilization of radio spectrum. Cognitive Radio senses the operating environment, learn and adapt in real time according to environment. The primary objectives of CR is to provide reliable communication and to utilize radio spectrum efficiently.

The term "Cognitive Radio" was coined by Joseph Mitola in 2002. In this paper, we use the definition adopted by Federal Communications Commission (FCC): "Cognitive radio: A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, access secondary markets."

The main challenge to the Cognitive radios is the spectrum sensing. We need spectrum sensing techniques for sensing the radio environment. There are three types of spectrum sensing techniques: energy detection, matched filter detection, and cyclostationary feature detection. These techniques have some limitations. Energy detection approach shows poor performance under low SNR conditions and cannot differentiate the interference from other secondary user sharing the same channel. Matched filter detection use is limited as there is hardly any information of primary user signal available at secondary user. These methods have various advantages but they also have some limitations. In order to address problems related to spectrum sensing in CR, a new concept of MIMO technology is introduced in Cognitive Radio.

This technique increases the spectral efficiency leading to improvement in the system performance. Here, multiple antennas are placed both on primary user as well as secondary user to increase the probability of sensing a target. MIMO technology is an efficient way to achieve the goal of reliable and accurate spectrum sensing.

Dynamic spectrum allocation and sharing schemes are required to fully utilize the spectrum resources. There have been rapid growth in past few years on Cognitive Radios. Cognitive Radio Technology provides future wireless devices with additional bandwidth, reliable communication and versatility for rapidly growing data applications. Recently, many signal processing techniques have been developed for spectrum sensing, and these can be classified as either non cooperative detection or cooperative detection. One of the first examples of a widely manufactured and distributed cognitive radio system is found in the cellular telecommunications arena. There are a lot of progresses on CR technology in the last ten years.

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The two main characteristics of Cognitive Radio are as follows (Alyidiz et al, 2006)

A) Cognitive Capability

Cognitive capability is capability to obtain the unused spectrum from Primary band in radio environment & provide best operating parameter for efficient spectrum utilization without any interference to primary user.

B) Reconfigurability

In CR reconfigurability, is same as SDR where the radio is programmed dynamically without any modification in hardware components. SDR is fully reconfigurable wireless device that adjust its communication parameters depending on user requirements or network. CR is capable of configuring both transmission and reception parameters in order to switch to different spectrum bands using appropriate protocols & modulation schemes with proper power level of signal.

Cognitive Cycle

The cognitive radio task starts with the passive sensing of RF stimuli & ends with action. The three important task in CR are:-

1.) Spectrum sensing which consists of the following
   - Detection of unused spectrum and sharing it without interference to primary users.
   - To detect primary holes.
2.) Spectrum analysis consists of following
   - Estimation of channel capacity information.
   - Predication of channel capacity for use by transmission
3.) Spectrum decision (Transmit power control and dynamic spectrum management):
   - The CR needs to select transmission parameters such as power level and spectrum holes.

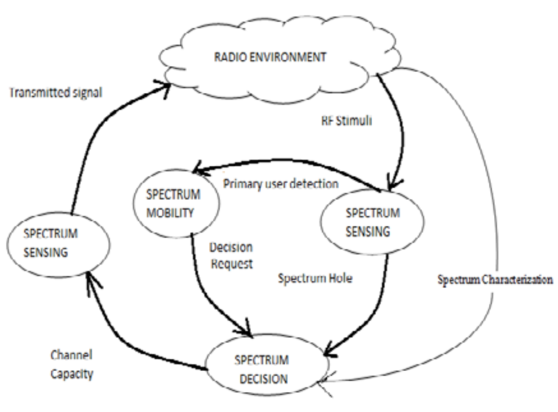

Fig.1. Cognitive cycle

The spectrum sensing task 1 and task 2 are carried out at receiver side and task 3 is carried out at transmission.

2. Spectrum Sensing

Spectrum sensing for cognitive radio is still an ongoing development. The major challenge in cognitive radio is to sense the primary spectra and quit the frequency band as soon as possible if the corresponding primary radio emerges in order avoid interference to Primary users. Spectrum sensing and estimation is the first step to implement cognitive radio system.

In evaluating the power spectra of incoming RF stimuli, the spectra is classified into three types:

- **Black spaces:** are occupied by lower local interferes some of time & unlicensed users (SU) should avoid those spaces at those times.
- **Grey spaces:** are partially occupied by lower power interferes but they are still candidates of unlicensed users.
- **White spaces:** are free RF interferes except for ambient noise made up of natural and artificial forms of noise.eg. thermal noise, transient reflections and impulsive noise.

The main aim of spectrum sensing is to decide between the two hypotheses,

Y(n)=w(n) : H0

Y(n)= x(n) +y(n) : H1

Where x(n)=h_s(n), h is the channel gain. w(n) is noise sample with mean zero and variance $2\sigma_w^2$. H0 = Absence of user, H1= Presence of user.

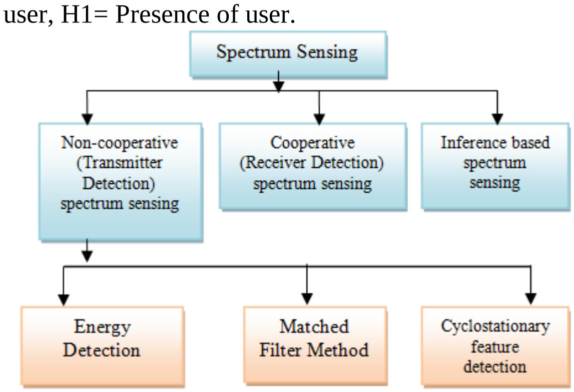

Fig 2. Spectrum sensing techniques

Spectrum sensing can be defined as examining the radio spectrum to determine the used or unused frequency bands. In EW applications, it is used to find the occupied frequency bands in the spectrum, whereas in cognitive radio, it is applied to detect the unoccupied frequency bands to communicate. This section discusses the three most common spectrum sensing methods reported in the literature.

2.1 Energy Detector-based Sensing:

Energy detector-based sensing is one of the most common sensing methods. It uses the energy of the received signal to decide on the presence of the signal. Figure 2 shows an implementation of this method. As seen in this figure, the received signal of interest is filtered, converted to a digital form, squared and integrated over the observation interval to obtain the signal energy. This energy is compared with a threshold to decide on the presence of the signal of interest. Energy detector-based sensing, also known as radiometry, is the optimal spectrum sensing method, when the information about the signal of interest is not known. It is easy to implement and has low computational complexity. Since the received energy is compared to a threshold in energy detector-based sensing, the threshold selection affects the performance of the method significantly. This method is also susceptible to uncertainty in the noise power.

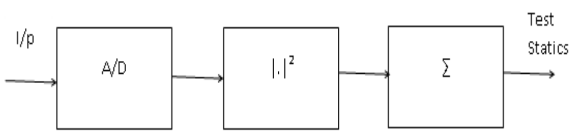

Fig 3. Implementation of Energy Detector

The output of energy detector in time domain is given as follows,

$$€_{time} = \sum_{n=1}^{N} |X(n)|^2 \quad (1)$$

Finally the test static is compared with threshold (λ) to determine whether the signal is present or absent.

$$\lambda \lesseqgtr €_{time} \quad (2)$$

The Energy Detector can be applied to different fading channel which includes Rayleigh fading channel, Rician fading channel and MIMO fading channel to calculate the probability of detection Pd and probability of false alarm Pf for different channels as follows [10]:

$$P_f = P\left\{Y > \frac{\lambda}{H0}\right\} = Q_m(\sqrt{2y}, \sqrt{\lambda}) \quad (3)$$

$$P_d = P\left\{Y > \frac{\lambda}{H1}\right\} = \frac{\Gamma(n, \lambda/2)}{\Gamma(n)} \quad (4)$$

1.a) Periodogram:

The periodogram method is a DFT based method to estimate power spectral density (PSD). The name periodogram comes from the fact that it was first used in determining possible hidden periodicities in time series.

FFT is given as:-

$$X(k) = \frac{1}{N}\sum_{n=1}^{N} X(n)\, e^{-j2\pi(k-1)(n-1)/N} \quad (5)$$

Where $1 \leq k \leq N$.

Where x(n) is discrete received signal, N is FFT size. Then we apply X(k) to an energy detector as follows:

$$€_{periodogram} = \frac{1}{N}\sum_{k=1}^{N}[X(k)]^2 \quad (6)$$

We sum N components of the output of square law device where X(k) is applied to, hence the variance of statistics fluctuates with respect to FFT size. In order to mitigate this fluctuation, we divide the statistics with FFT number in order to hold the variance constant.

2.2 Matched Filter Method:

The optimal way for signal detection is a matched filtering since it maximizes received SNR and also requires short time to achieve a certain probability of false alarm or probability of miss detection as compared to other methods. The other hand matched filtering requires perfect a priori knowledge of licensed users' features such as bandwidth, frequency, modulation type, etc. to demodulate received signals. Therefore it needs dedicated signal receivers for each signal type that leads to the implementation complexity and large power consumption as various receiver algorithms need to be executed for detection.

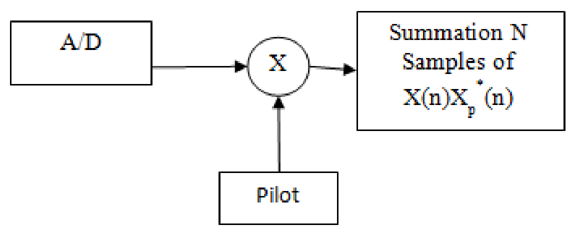

Fig 4. Block diagram of Matched filter

Considering the fact that it requires perfect knowledge on signal features such as bandwidth, operating frequency modulation type and order, pulse shaping and frame format, and it also needs large power consumption it's very impractical to implement in cognitive radios.

2.3 Cyclostationary method:

Another detection method used is the cyclostationary feature detection which depends on the fact that modulated signals are generally coupled with sine wave carriers, pulse trains, repeating spreading, hopping sequences or cyclic prefixes which result in periodicity and their statistics, mean and autocorrelation, exhibit periodicity in wide sense. This periodicity trend is used for analyzing various signal processing tasks such as detection, recognition and estimation of the received signals. Despite having a drawback of high computationally complexity, cyclostationary feature detection performs satisfyingly well under low SNR regimes due to its robustness against unknown level of noise. Another saying; it is not susceptible to noise levels as energy detection.

3. Multiple Antenna Techniques

Multiple antenna techniques for wireless communications provide higher data rates than single antennas. Various antenna techniques include: SISO SIMO, MISO & MIMO. Multiple antennas are in context of MIMO communication system and are used to improve the performance of system in terms of BER. In MIMO systems, the transmitter transmits signal over multiple channel through multiple antennas, the receiver acquires information about the channel between transmitter and receiver, and then performs signal processing to estimate the signal received through each antenna.

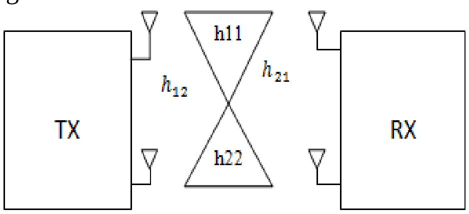

Fig.5 MIMO system model

Mathematically ,

$$Y=HS+N \quad (7)$$

H is channel matrix and its elements are independent. S is signal and N is the noise.

Advantage:

- Sensitivity to fading is reduced.
- Improved bit error rate performance.

Table 1: Comparison of Spectrum Sensing Techniques

Spectrum Sensing Techniques	**Pros**	**Cons**
Energy Detection	Does not require prior knowledge of signals. Easy to implement	High false alarm due to noise uncertainty. Very unreliable in low SNR.
Matched Filter Detection	More robust to noise uncertainty and better detection in low SNR regimes Require less signal samples.	Require precise prior information about certain waveform patters of primary signal. High complexity.
Cyclo-stationary Feature Detection	More robust to noise uncertainty and better detection in low SNR regimes. Require less signal samples	Specific features e.g. cyclo-stationary features must be associated with primary signals. Particular features may need to be introduced .eg ofdm.

4. Simulation and Results:

The fig 6.a and 6.b shows Probability of Detection Vs PFA & Probability of Miss Detection VS PFA for Time Domain BPSK where SNR is fixed to 1.500.

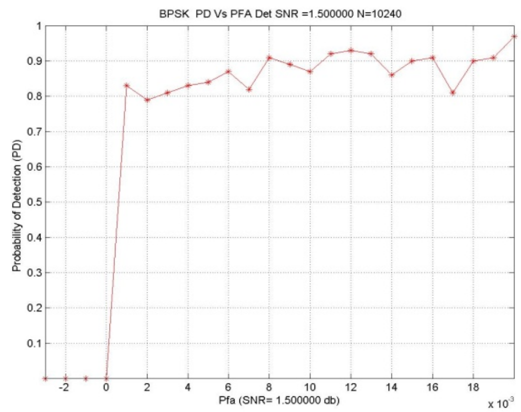

Fig 6.a. PD Vs PFA for Time Domain BPSK.

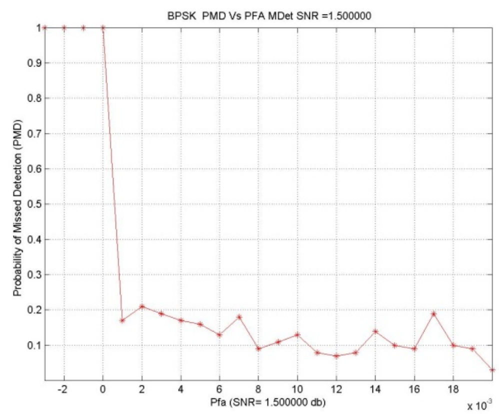

Fig 6.b. PMD Vs PFA for Time Domain BPSK.

5. Conclusion

In this paper, we examined various spectrum sensing techniques in cognitive radio using multiple antennas. Cognitive radio being the most prominent and widely used technology helps improve spectrum usage. Multiple antennas provide improved sensitivity to fading over SISO systems.

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